Global Calculation of β-strength Functions for Modeling Antineutrino Spectra and Stellar EC Capture Rates

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In nuclear fission of ^{235}U and other actinide nuclei, many hundreds of different unstable fission-product nuclei are created. Stable nuclei in the fission-product region have a lower proton to neutron ratio than the parent fissioning actinide nucleus. The fission products are therefore unstable with respect to radioactive decay. These products decay by the so-called β-decay process in which a negative electron is emitted and a neutron is converted to a proton. The resulting product may in turn decay. The process continues until a β-stable nucleus is reached.

In the β-decay of a *parent* nucleus an electron is emitted and a *daughter* nucleus is created, either in its ground state or in an excited state. In our model of β-decay [1] we calculate the wave function of the initial state in the parent nucleus and the wave functions of all possible final states in the daughter nucleus. In the next step we calculate the transition rates to the various states in the daughter nucleus. By summing up all possible transitions we calculate the half-life $T_{1/2}$ of the decay. By summing up all the transition rates to states above the neutron separation energy S_n we can calculate the fraction of the decays that lead to delayed-neutron emission and the corresponding delayed-neutron emission probability P_n. We have previously calculated these quantities globally for all nuclei of interest and entered relevant calculated data in Los Alamos National Laboratory databases such as ENDF and CINDER90, for those nuclei where experimental data are unavailable [2, 3].

However, our models are able to provide much more complete details about nuclear β-decay than just the half-lives and delayed-neutron emission probabilities, namely the decay rates from the initial state to each of the individual energy levels in the daughter nucleus. These decay rates are the products of a nuclear matrix element (called β-strength function) and *phase-space* factors related to the available phase space open to the electrons and antineutrinos associated with the decay. When the decay rates to the individual daughter states are known, the associated antineutrino spectra can be calculated in a straightforward manner. This is important in homeland defense applications such as determining the fuel status of a reactor by antineutrino monitoring. Other applications exist in astrophysics. For example nuclei in extreme stellar environments characterized by high pressure and high temperature can transmute to other nuclei through electron capture (EC) also in cases where EC on a nucleus is energetically impossible for "free" nuclei on Earth. Under normal conditions only

***Table 1—** Calculation of Possible Gamow-Teller Decays from the doubly-magic Nucleus $^{78}_{28}Ni_{50}$. Column 1 is the excitation energies of the populated states in the daughter nucleus. The second column is the strength function or the nuclear matrix element between the parent and daughter state. The third column is the intensity of the decay in percent of the total decay rate. Finally the last column is the calculated log(ft) value. We have calculated thousands of these decay schemes.*

E (MeV)	β-Strength	Intensity (%)	log(ft)
2.76	0.1151763 E+00	40.4129	4.5547
3.95	0.4139639 E-01	5.9869	4.9991
4.23	0.6269132 E-01	7.1315	4.8188
4.51	0.3125310 E-02	0.2781	6.1212
5.46	0.1176526 E+01	40.5529	3.5455
6.93	0.1120543 E+01	5.3425	3.5666
6.93	0.5163683 E-01	0.2459	4.9031
8.29	0.1388374 E-01	0.0029	5.4735
9.70	0.1101238 E+01	0.0000	3.5742
10.36	0.3756241 E-01	0.0000	5.0413
13.51	0.2180125 E+00	0.0000	4.2776
13.66	0.1066086 E-01	0.0000	5.5883

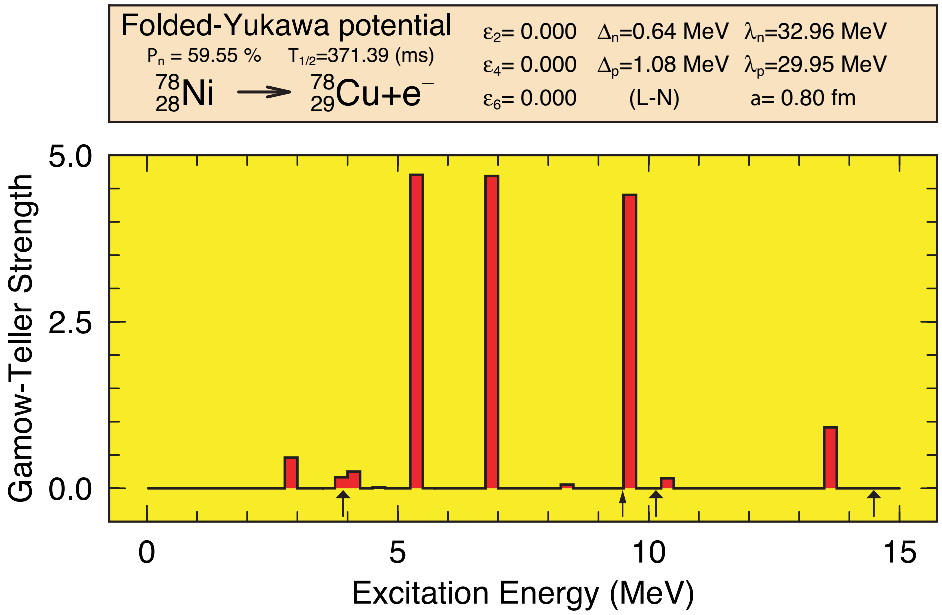

Figure 1— ***Calculated histogram of the β-strength function of $^{78}_{28}Ni_{50}$ decay. The thin arrow represents the decay energy or Q value. No decays can occur to states above this energy. The wider arrows represent (from left to right) the 1n neutron separation energy S_{1n}, the two neutron separation energy S_{2n}, and so on. Decays to states above S_{1n} lead to neutron emission.***

nuclei on the proton-rich side of β stability transmute by capturing electrons. In some stellar environments nuclei on the neutron-rich side of β stability can capture electrons because, loosely speaking, the electrons are pushed into the nuclei in the high-pressure environment.

It turns out that the quantities needed in the various applications are most easily calculated starting from the nuclear transition matrix elements to the various daughter states, the β-strength function. It is therefore this quantity we tabulate. We have calculated the strength functions for β decay from thousands of different parent nuclei. We have calculated the strength functions associated both with negative electron emission and with EC, also on the *neutron-rich* side of β stability.

We give an example of a calculated β-strength function in Fig. 1. A table of all the individual matrix elements (β-strength) and the associated decay rates for this decay are given in Table 1. The decay rates depend on the *Q*-value of the decay. Since this has not been measured, we obtain the *Q*-value of the β-decay from our table of calculated masses [2, 4].

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[4] P. Möller, J.R. Nix, W.D. Myers, and W.J. Swiatecki, *Atomic Data Nucl. Data Tables* **59**, 185 (1995).